**Destiny is not what you have got,**

*but what you can make out of whatever you have got.*

In the history of human endeavor to intervene and harness the natural resources for its welfare, Sardar Sarovar Project emerges as one of the very few projects across the globe that have played a significant role in bettering the quality of life for millions. With its unique features and unparallel dimensions, SSP has undoubtedly occupied a remarkable position on the world atlas of water resources development. Apart from its manifold benefits in terms of long term water, energy and food security and thereby sustainable development of Gujarat State, SSP has overcome many engineering and technological challenges during its journey from concept to its present stage. In true sense, it is the Engineering Marvel. TIME magazine, in 1994 described the Narmada Project as one of the “Eight Modern Wonders Abuilding”. Such a recognition brings to the Project that glory which the Tajmahal enjoys in the field of ancient structures.

One of the most studied water resources projects of the world, SSP has successfully adopted path-breaking approaches for arriving at the technological solutions at every step of its implementation. It has been a forerunner in terms of offering new dimensions and evolving fresh engineering standards – be it planning, designing or implementation. Engineering issues dealt with in the different project components like dam, hydropower, canal, canal structures and so on, had no off the shelf solutions existing anywhere in the world. “Necessity is the mother of invention” – this has been absolutely true in the case of SSP and has led to many distinctive elucidation.

From the view point of integrated development with basin approach, SSP is a part of much larger plan of utilization of the whole course of river Narmada – the Fifth largest in the country, comprising 30 Major Dams, 135 Medium Dams and about 3,000 Minor Dams along the 1,312 km length.
Sardar Sarovar Dam is a concrete gravity dam across river Narmada, 1210 meters (3970 feet) in length and with a maximum height of 163 meters above the deepest foundation level, is constructed upto the crest level of spillway i.e. 121.92 m.

The Dam – From Alignment to Achievement

It will be the third highest concrete dam (163 meters) in India, the first two being Bhakra (226 metres) in Himachal Pradesh and Lakhwar (192 meters) in Uttar Pradesh.

In the initial phase of construction of Sardar Sarovar Dam, unprecedented challenges were successfully overcome by the Project Engineers. Some of the noteworthy achievements in the design and execution comprise River Diversion Scheme, Submersible Cofferdams under flowing water conditions across deep river channel, excavation of open cut diversion channel, providing gated construction sluices etc. 10 temporary construction sluices, each of size 2.15 m x 2.75 m. were provided in the body of the spillway at RL 18 m, which were closed in February, 1994. Another set of 4 permanent river sluices are provided at RL 53.0 m.

Construction of Cofferdam for diversion of river flow
Construction Sluices in the Main Dam

Treatment of geological fault in the dam foundation involved 2,14,000 m$^3$ of excavation, 2,50,000 m$^3$ of rock excavation, 2,56,000 m$^3$ of pre-cooled concrete and 53,000 tonnes of reinforcement steel. Treatment of argillaceous sandstone in two layers on the right bank and red bole layer on the left bank was carried out by providing a grid of concrete shear keys (3.0 m wide and 3.5 m deep) parallel and perpendicular to the dam axis aggregating to 12 km length. With such a vigorous treatment, the design of the dam allows for a horizontal seismic coefficient of 0.125g and it also covers an additional risk due to reservoir induced seismicity. Thus foundation treatment itself was more challenging than construction of any major dam even!
In terms of the volume of concrete involved for gravity dams, this dam will be ranking as the second largest in the world with an aggregate volume of 6.82 million m$^3$. The first is Grand Coule Dam in USA with a total volume of 8.0 million m$^3$.

For mass concreting, a vibratory Grizzly with 2 feed hoppers, 2 Grizzly feeders, 2 Two-way Gates, 1 Jaw-crusher and 4 conveyor belts inclined at a maximum angle of 15° running at a speed of 1.5-2.0 m/s was installed. The capacity of conveyor belt system used was 1000 tonnes/hr and it had a total length of 4.5 km.

In the Aggregate Screening Plant, 2 reclamation tunnels each having 5 electrically operated vibro-feeders of 500 tonnes per hour were used. 6 Nos. of Cement Silos with total capacity of 12000 tonnes were used for storage of bulk cement using pneumatic pressure. To take care of heat of hydration during mass concreting, a Chilling Plant comprising 6 Chillers with total installed capacity of 1350 tonnes of refrigeration was used along with an Ice Plant consisting of 8 Ice Makers with aggregate installed capacity of 300 tonnes per day of flaked ice. A fully automatic computerized Batching and Mixing Plant (imported from CIFA, Italy) with production capacity of 330 m$^3$/hour was used.

Two Cable Cranes used for placing the concrete – each having 28 tonne capacity and spanning more than 1.5 km were the longest ever in the world.

Concrete placement Bucket with capacity 9 m$^3$, covering maximum width of 120 m
This dam with its spillway discharging capacity of 87,000 m³/second (30.70 lac), will be the third in the world, Gazenba (1,13,000 m³/second) in China and Tucurri (1,00,000 m³/second) in Brazil being the first two.

For chute spillway, 7 Radial gates each having size 60' x 60' and for service spillway, 23 Radial gates of size 60' x 55' are to be provided to negotiate the design flood.

The River Bed Power House with an installed capacity of 1200 MW is an underground power house stationed on the right bank of the river located about 165 meters downstream of the dam. It has six number of Francis type reversible turbine generators each of 200 MW installed capacity, supplied by M/S Sumitomo Corporation, Japan and M/S BHEL.

The runner – with a diameter of 6.95 m (23 feet) weighing 120 tonnes each, produced in one piece.

Lowering of Steel Ring in RBPH
These six units have been commissioned in a phase manner during February 2005 to June 2006.

Access Tunnel and Machine Hall of RBPH

The CHPH is a surface power station in a saddle dam on right bank of the reservoir having total installed capacity of 250 MW (5 x 50 MW). These five units have been commissioned in a phased manner during Aug-04 to Dec-04. These units can be operated with minimum reservoir water level of 110.18 meters.

Narmada Main Canal

The Narmada Main Canal, having a length of 458 km in Gujarat and further extended to 74 km in Rajasthan, is world’s largest concrete lined canal with discharge carrying capacity of 1133 $\text{m}^3/\text{second}$ (40,000 cusecs) at its head. This canal designed to annually convey 11.7 BCM of water to quench the thirst of Gujarat and Rajasthan has been completed and water has been flowing all through since March 2008. It is envisaged to use this canal not only for conveyance but also for storage of water to improve the response time of the system. At full supply depth, this canal can store 220 MCM of water – a volume
which can serve domestic needs of a mega city like Ahmedabad for the entire year! This storage available round the clock is even more than the capacity of dams like Watrak and Bhadar of Gujarat State.

**Building the Lifeline – to convey Elixir of Life**

**Mechanised Paver Lining on Side Slope for conveying 11.7 BCM annually**
This unique canal is a contour canal having command area of 18,45,000 hectare on its left bank. Along its length of 458 km i.e. upto Gujarat-Rajasthan border, total 634 structures are constructed of which 114 are control structures (Head Regulators, Cross-regulators and Escapes), 231 are cross-drainage works for crossing natural streams and other canals (Aqueducts, Syphon Aqueducts, Canal Syphons, Drainage Syphons and Superpassage) and 289 structures are communication structures (Road and Railway Bridges).

**American Concrete Institute Award for Excellence – 1991:**

*Canal Lining of Narmada Main Canal - Most Outstanding Concrete Structure in India*

The Head Regulator – offtaking structure of the NMC at Ch.0 km is 82.6 m long having 5 Radial Gates of Size 12.20 m x 13.50 m. Total 12 Thousand Cubic metre concrete was poured and 490 tonne steel was consumed for completing the structure.

Some of the structures on Narmada Main Canal are simply magnificent from the size, technical complexity, design and construction points of view. Noteworthy structures like Orsang Aqueduct, Mahi Aqueduct, Watrak Canal Syphon, Sabarmati Canal Syphon, Escape structure on river Sabarmati, Y-Junction (offtake point of Saurashtra Branch Canal), Banas Canal Syphon, Saraswati Canal Syphon etc. are nothing but the testimony of the engineering and technological skills of the project engineers. Right from conceptualization
to its planning, design, construction and operation, the Narmada Main Canal has faced many technical issues – each one deserves a special mention. The range of design challenges involved in these structures included high discharges leading to larger barrel size, typical foundation problems, huge loading, long-term consolidation settlement, design of leak-proof joints at the locations vulnerable to differential settlement, seismic factors and dynamic response of the structure, magnitude of fall, longer spans, limitation of the available materials and products (for example bearings) and so on for which no ‘off the shelf’ solutions were available. State of the art technology including mathematical and physical model studies was harnessed to arrive at the safe and yet economical solutions. Various research institutions of national and international repute were also consulted to resolve many such issues. From construction point of view, mechanized paver lining on side slopes, dewatering on major river crossings, slip formwork for speedy construction etc. were the pioneering efforts made in the construction history of the whole country.

*Orsang Aqueduct on NMC at Ch. 48.59 km*

The 548 m long and 82.3 m wide Aqueduct spanning across the river Orsang is another unique structure having 27 spans of 20.30 meters each. The height of the super structure is 21.6 m above the river bed. The foundation consists of Pile foundation for Piers and open foundation for Abutments. The water flow of 1126.38 m³/second is carried across the river through super structure of 3 monoliths having 3 barrels (box-structure) each of 7.0 m. width and 6.93 m. height. 2,23,200 m³ of concrete and 16178 tonne of steel for reinforcement has gone in making this mammoth structure.
**World’s largest Aqueduct on river Mahi – during construction**

Mahi Aqueduct constructed for crossing the River Mahi at NMC Ch. 142.86 km. is 602.5 m long and contains 8 Barrels of Size 6.10 m x 7.6 m. Total 387 Thousand m$^3$ concrete was poured and 22904 tonne steel was consumed for completion of the structure, which took more than 9 years! Total concrete volume used in this structure alone is more than that used in the Burj Dubai – the world’s tallest tower (3,30,000 m$^3$)!

Each of its 634 structures is unique in the case of Narmada Main Canal. Just to cite one of them, at Ch. 196.188 km, the Narmada Main Canal crosses a major river Watrak which has a routed design flood discharge of 14,500 m$^3$/second – about 16 times that of the NMC discharge at the crossing site (977 m$^3$/second). Constructing a 410 m long canal syphon having 10 barrels of size 6.0 m X 7.25 m each on a highly compressible clayey strata (CH type) was a real challenge. After thorough investigations, alternative designs and interaction with the experts, three fold remedial course of action was evolved comprising sand drain as a foundation treatment, staggered construction leaving gaps to accommodate differential settlement and pre-loading of the partly constructed structure. With a primary objective of pre-consolidation (90% in 125 to 166 days) and secondary objective of strengthening of foundation strata, 2038 nos. of vertical sand drains each having diameter of 200 mm and depth of 12 to 25 m (total length 42653 m) were resorted to.

For controlled preloading purpose, in addition to the dead load of partly constructed barrels, a superimposed loading of 23 to 26 t/ m$^2$ was required. This was achieved by 600 nos. of cast-in-situ concrete blocks and 6000 nos. of pre-cast concrete blocks (each of size 1.25 m X 1.25 m X 1.0 m) with total concrete volume of 8800 m$^3$. In addition to this, 1,30,000 m$^3$ of natural aggregates were used.
After achieving pre-consolidation in 125-166 days, the structure was unloaded and the concrete blocks were used in the protection works, launching apron and also in buoyancy concrete. Usable natural aggregates after unloading were used in concrete work and other items of the structure.

\textit{Watrak Canal Syphon - Preloading with concrete blocks and natural aggregates}

The Canal Syphon, built across river Sabarmati at ch. 229.92 km of the Narmada Main canal (NMC) is 518 m long and 71.25 m wide with a discharge carrying capacity of 881.634 m$^3$ / second. For constructing 3 monoliths having 3 barrels (box-structure) each of 6.25 m. width and 6.50 m. height-supported over raft foundation, 8,23,000 m$^3$ of earth-work and 2,13,750 m$^3$ of concrete have been used. The canal siphon crosses the river Sabarmati at 15 m below the bed level of Sabarmati river.

There are 38 branch canals offtaking from NMC to serve a vast command of 1.8 million hectares spread in 15 districts. The largest of these is Saurashtra Branch Canal which has a length of 104.46 km and discharge of 424.80 m$^3$ /second. To negotiate the peculiar land topography with a falling ground from Ch.0.0 to 59.0 Km by about 52.0 m and thereafter from 59.0 to 104.460 Km a rising ground by about 66.0 m before tailing into Bhogavo - II reservoir, three power stations at fall points and five pumping stations at lift points are planned. Total 48 MW hydro power is planned to be generated at the three fall structures at Ch. 5.15 km, 17.76 km and 32.94 m each having a vertical drop of 10.9 m. Thereafter total lift of 71 m is provided by a series of five Pumping Stations at Ch. 66.518 km, 77.165 km, 87.95 km, 93.205 km and 102.84 km with pumping head ranging from 10.8 m to 17.025 m. In these five pumping stations, which are the largest in India, total 26 Concrete Volute Pumps each having capacity of
20 m³/second and 22 Vertical Turbine Pumps of 5 m³/second capacity each. A single Concrete Volute Pump of 20 m³/second capacity can serve the daily water requirement of Burj Dubai in just 48 seconds!

*SBC Pumping Station No. 1 during construction*

*SBC Pumping Station No. 1 – after construction*
The Canal Syphon built across river Banas at Ch. 360.011 km of the Narmada Main Canal (NMC) is another exemplary case of engineering skill. The Narmada water flow of 387.415 m$^3$/second will be carried across the river Banas through this 700 m long and 53.2 m wide Canal Syphon structure having 2 monoliths of 4 barrels each of 5.50 m width and 5.60 m height - supported over raft foundation. Deciding the exact location of this structure and its length was indeed challenging because of undefined river gorge and peculiar hydrology causing flash flood in the form of sheet flow. Extensive physical model study at Roorkee and mathematical model study by CWPRS helped in arriving at the final decision. 203761 m$^3$ of concrete, 13453 Tonne reinforcement, and 61200 Tonne cement is consumed in making this mammoth structure.

Physical Model Study for Banas Canal Syphon – carried out at Irrigation Research Institute, Roorkee
As is evident from the above the Sardar Sarovar Project has adopted many innovative and path-breaking approaches in planning, design, construction and operation, all of which have no parallel in the whole world. In future too, the Project is all set to have further unique features like SCADA based Remote Monitoring and Control System, the longest Branch Canal i.e. Kachchh Branch with 360 km length involving many technical challenges enroute while passing through difficult topography and desert area which falls in Seismic Zone V. Thus the path has not been smooth nor there were readily available answers. But that only makes SSP an Engineering Marvel in its true sense!

Summing Up

This paper is only an attempt to highlight some of the major features of Sardar Sarovar Project coming to my mind. My direct touch with this Project ended with renunciation of my office as the Minister of this mega scheme. In preparing this paper, I have been considerably assisted and helped by my erstwhile colleagues and especially Dr. Mukesh Joshi. Hopefully this may place in some perspective the path-breaking efforts which blasted the myth that our engineers might fall short of the talent required in executing this unique project. The unique engineering features, some of them “First” and some of them “The largest” on this globe, bear a testimony to the technical skills,
competence, talent and teamwork our engineers and also the contracting agencies put in to realize this dream called “SSP”. On the other hand the sacrifices made by those who are required to be resettled and also the farmers and land owners who cooperated with the process deserve a special mention. Tremendous emotional support that the NGOs and the people of Gujarat and also outside the state extended to this Project is now a well known history leading to this phenomenon. The contents in this paper may therefore be viewed as a merely miniscule description of many noteworthy achievements. It is hoped that the contents presented will be interpreted with these limitations in mind.